FIVE YEARS OF CACAO RESEARCH

1930–35

Via colendi haud facilis.

[*Reprinted from "Tropical Agriculture," Vol. XII, No. 7.*]

Price **One Shilling.**

TRINIDAD:
PRINTED BY THE GOVERNMENT PRINTER,
GOVERNMENT PRINTING OFFICE,
PORT-OF-SPAIN.

1935.

PUBLICATIONS ISSUED.

FIRST ANNUAL REPORT ON CACAO RESEARCH, 1931, pp. 43+1 plate +12 text figs. 1*s*. Net.

SECOND ANNUAL REPORT ON CACAO RESEARCH, 1932, pp. 40+xii +4 plates+34 text figs. 5*s*. Net.

THIRD ANNUAL REPORT ON CACAO RESEARCH, 1933, pp. 71 +3 plates+8 text figs. 5*s*. Net.

FOURTH ANNUAL REPORT ON CACAO RESEARCH, 1934, pp. 87 +4 plates+12 text figs. 5*s*. Net.

Copies of all the above publications may be obtained on application to the Editor, *Tropical Agriculture*, Imperial College of Tropical Agriculture, Trinidad, B.W.I.

FIVE YEARS OF CACAO RESEARCH, 1930-35.

INTRODUCTION.

BY

Sir GEOFFREY EVANS, M.A., C.I.E.,
Principal, Imperial College of Tropical Agriculture.

ALTHOUGH prior to 1930 there had been many researches carried out on cacao in different parts of the world, it is perhaps safe to say that this crop had not received the same amount of detailed attention as other tropical agricultural products of major economic importance. At the time when the Cacao Research Scheme was launched at the Imperial College of Tropical Agriculture it represented in important respects a new departure. It was the first organized attack, by a staff specially appointed for the purpose, on the botanical and soil problems encountered in the cultivation of this important crop. It was also the first investigational work on this crop to be financed jointly by producers and manufacturers in the interests of the industry as a whole. The co-operation of the cacao-producing countries of the British Empire and some of the leading manufacturers of cocoa and chocolate enabled broad aims to be adopted. In a preface to the First Annual Report on the Scheme, I recorded the history of its genesis, and there showed how logically it developed from the conception of long range research that has been laid down as the appropriate function of institutions such as this College.

As originally conceived, the Scheme was intended to run initially for five years and funds were provided for that purpose. It was believed that during this period certain preliminary researches would be completed, and it was anticipated that their results would inevitably demonstrate the necessity for continuation and extension. The four annual reports that have now been published have established the fact that these preliminaries have been accomplished, and also that much further work requires to be undertaken. In this connection it must always be remembered that we are dealing with a perennial crop in which the final results as measured by crop yields are naturally much slower to obtain than in the case of annual crops.

The first five-year period is now drawing to a close, and as the whole organization is coming up for review a concise statement of the position should interest not only the present subscribers to the Scheme but also all who hold a stake in the cacao industry. The annual reports are necessarily somewhat lengthy and complicated by scientific detail, and I have accordingly requested the officers responsible for the planning and direction of the technical work to prepare the two summaries that form this bulletin. Professor E. E. Cheesman describes the botanical work carried out by Messrs. F. J. Pound and E. E. Pyke, and Professor F. Hardy the chemical and ecological investigations of Mr. J. A. McDonald.

The criticism has been sometimes advanced that the results obtained are more particularly applicable to Trinidad and West Indian conditions, but a perusal of these reports will show that such criticism is not well founded. The Central Cacao Scheme had to have its headquarters somewhere and in many ways Trinidad is the most suitable centre for this work. This island can show a range of cacao types probably the widest in the world, and thus affords an unrivalled field for selection work and for studies of compatibility, physiology and similar problems. It also possesses a considerable variety of soil types and varying climatic conditions, and so affords good conditions for pursuing the study of the ecological requirements of the plant. In reading these summaries therefore, it should always be borne in mind that while of necessity the Trinidad crop and Trinidad conditions have been utilized, they have been used for the purpose of establishing general principles which are applicable to other countries and other classes of cacao. This procedure is strictly in accordance with the conception of long range research and leaves to the various Colonial Agricultural Departments or research workers in other parts, the necessary modification of details to suit their particular circumstances. It was never supposed that all the problems of a crop which is grown in four continents could be studied in one place, but there is still a vast amount of fundamental knowledge to be acquired about cacao that can be applied universally when available. It is the policy of those in charge of the Cacao Research Scheme to select its problems from among those which have the widest bearing.

In times such as these, when there is apparent over-production and prices are so phenomenally low, it may seem strange to some of our readers that increased yields should be the main object of our research. There is nothing really illogical in this. It is really a matter of the essential difference between *production* and *productiveness*. The latter is mainly a question of increasing the yield per acre and is an index of efficiency, and enhanced efficiency is the final aim of all agricultural research. Cacao, with one or two minor exceptions perhaps, is grown at present by extensive methods. It is treated more as a forest than an orchard crop. Large areas have been relied on in the past to give the necessary production with a lack of attention to details of cultivation that compares unfavourably with the methods employed on most other orchard and plantation crops. Plantations that have been kept up under these conditions are not in a position to stand up against a long period of depressed prices. They rapidly go down in yield and there are already signs that they are likely to succumb more readily to the inroads of diseases and pests. It seems probable that intensive methods based on a high yield per unit area such as are recommended by the Research Scheme would stand a much better chance of withstanding the economic blizzards of the future.

Concerning the progress made towards specific aims, the summaries speak for themselves, and it only remains for me to stress the fact that a continuation of these researches depends on the judgment they receive from the industry. Considering the depression through which that industry has been and is still passing, its support has hitherto been most encouraging. Nevertheless, the sums contributed for the first five years fell below the original estimates, although those estimates were very modest in proportion to the interests involved. During the latter part of the period funds have been barely sufficient to carry on the work, and I wish to pay my tribute to the loyalty and enthusiasm of the technical officers employed by the Scheme for the way they have carried out their duties under considerable financial difficulties.

At the present stage, if the results achieved are deemed to have justified the relatively small sum expended in obtaining them, it will be desirable for the basis of the research to be broadened. There are important lines of research which it has been quite impossible to open at all. Although it may prove impossible to provide additional funds until times improve, it should be pointed out that failure to consolidate, at the very least, the advances already made, would be disastrous.

In conclusion, I would like to express my special thanks to the Director and officers of the Trinidad and Tobago Agricultural Department for their co-operation. The facilities afforded by an established experimental station such as River Estate have been of incalculable value. In the same way, the cacao planters of this Colony have followed the research with the greatest enthusiasm, and their help and good will have been of the greatest encouragement to us. It is significant that already many of them are beginning to adopt certain measures that have emerged as the result of this research work.

I should like to record my appreciation of the close co-operation that has taken place between the Cacao Research workers and the other officers at the College. It is not generally understood that cacao receives a great deal of attention from several of the College departments which are not connected financially with this research. The problems of cacao economics have been receiving detailed attention for years past, and the Professor of Economics has kept in close touch with the work. Similarly close touch has been kept with the Departments of Mycology and Entomology, who have carried out investigations on certain cacao diseases and pests, while quite recently the officer in charge of the Low Temperature Station has collaborated in carrying out storage tests on cacao pods, which should have an important bearing in the future in connection with the possibility of interchange of varieties and the introduction of improved types. To all these officers my special thanks are due.

THE BOTANICAL RESEARCHES.

By E. E. CHEESMAN, M.Sc.

Aims.

The general aim of these researches was broadly defined at the outset as "the collection of information necessary for improvement of both yield and quality in the cacao crops of the Empire, with the economic object of increasing the profits of both the grower and the manufacturer." The more specific aims depend on the basic principles of crop improvement. The grower, however skilled and careful, cannot get the best results from inferior trees, and there are undoubtedly many trees on existing plantations that do not pay for their keep. This consideration leads us to *selection*, or an attempt to find some of the best trees in the population, and to *propagation* or attempts to multiply them, when found, to replace the mediocre and the bad. It is worth noting that the breeding of new varieties has no place in the immediate programme, the reason being that the sorting out of existing types is more urgent. Cross breeding operations have gone on in Nature for hundreds of years already, and it behoves the plant breeder to take advantage of the fact before attempting, with little to guide him, to go further.

Important as the constitution of the tree is, however, even the best of trees will not develop its powers without appropriate treatment, and this second consideration leads us to general studies of the way in which the cacao tree lives and grows and builds up its crop. The soil and the environment generally have much to do with the final yield, and these studies are therefore in large part the work of the Chemical Section, but they have also aspects strictly botanical as well as many calling for close contact between the two branches. We have called the more botanical aspects *studies of fruitfulness* because the setting and subsequent development or failure of the fruits were selected for first attention.

Selection.

The successive steps in the process of genetic selection have been as follows :—

1. *Analysis of Requirements.*

The "best" trees are not necessarily those bearing the highest quality of produce, or even those giving the highest yield. They are those most *profitable* when yield, quality and costs of cultivation are all taken into account. The conditions of the cacao industry indicated that increased productiveness should be placed first, and quality (so far as it depends on the tree) second. The two cannot in practice be separated, but we did in fact attack first the problem of finding the highest yielders, and as it happened the quality problem partly solved itself. Yield per tree depends on the number of pods borne and the amount of cacao in each pod. Yield per acre, which is more important, depends also on the size of the tree, governing the number of effective trees per acre. Knowing that cacao trees vary widely in the number of pods they bear, we had first to find out whether the heaviest bearers were also the highest yielders.

2. *Determination of Sampling Constants.*

As large numbers of quantitative measurements had to be made, and had to be of known precision, the first step was to determine the size of sample necessary to give a dependable result. Investigations of sampling methods occupied one crop season, but saved time in the long run. Thirty pods were found to constitute an adequate sample for characterising the fruit of any one tree, giving means for some measurements within five per cent. and for others within ten per cent. of the truth (1931 Report).

3. *Quantitative Survey of Trinidad Cacao.*

Standard pod samples were examined from nearly a thousand trees (actually 950) distributed in twelve blocks in different parts of Trinidad. These trees served as a fair sample of the population on good estates, and indicated the range of variation within which selection had to work. The range found is concisely expressed in the following table from the 1932 Report, the modes for all Trinidad being probably a little on the poorer side in each case.

Dimension.	Lower Limit.	Upper Limit.	Mode.
Length ..	10.5 cms.	23.5 cms.	16.0 cms.
Diameter ..	6.1 cms.	10.6 cms.	8.0 cms.
Ratio (Shape) ..	1.3	2.7	1.95
Shell thickness	0.8 cms.	2.4 cms.	1.4 cms.
No. beans ..	15	45	34.5
Pods to the pound ..	6	22	10.5
Weight of a single bean ..	1.1 gms.	5.6 gms.	3.2 gms.

4. *Qualitative Survey.*

During the quantitative survey, extensive notes were also made on such characters as colour, shape and surface texture of pods, in the hope that some correlation might be found between such easily observable features and the value of the trees showing them. Success would have meant the saving of much time-consuming measurement, but it was found that good trees may occur in almost any of the 110 "type" classes recognized. Consequently qualitative observation could not replace quantitative measurement although it provided useful indications in many cases. (1932 Report.)

5. *Fixing of First Standard.*

The quantitative survey showed that the most important variation affecting yield, apart for number of pods borne, is the value of the indiv dual pod. The table above shows that some trees bear pods of which six make 1 lb. of dry marketable cacao (1) whilst most frequently 10 or 11 and from some trees 22 pods are needed

(1) The quantity "pods to the pound" is calculated from the mean weight of *wet* cacao per pod for the tree in question, assuming 60 per cent. loss in weight in fermentation and drying. The factor is sufficiently accurate at this stage, considering the great variation in wet cacao weight from tree to tree.

to give the same weight. Rather wider extremes have been found since. This result proves that number of pods borne means very little until corrected by " pod value ".

The value of a pod cannot always be judged from its external size, because of the great differences in shell thickness. It must be judged on wet cacao weight, and first selections were based on this quantity alone, a specially devised spring balance being employed for its rapid determination.

The selection limit was placed at $7\frac{1}{2}$ pods to the pound. About two per cent. of the Trinidad tree population have pods of which $7\frac{1}{2}$ or less make a pound of dry cacao, and this two per cent. includes a certain proportion of heavy bearers. The other 98 per cent. also includes some heavy bearers, which have not been altogether neglected, but, for reasons that will appear, work from this point was mainly concentrated on finding and tagging 1,000 trees passing this standard of pod value. (1932 Report.)

6. *Considerations of Quality.*

Quality in cacao depends on many factors, of which some cannot be studied in the preliminary phases of research. Size of bean, however, is one that can be dealt with. The table reproduced above shows that the mean wet weight of single beans from different trees varies from 1.1 to 5.6 grammes, being most usually about 3.2 grammes in the sample examined. There is therefore scope in the population for improvement, if it can be obtained without sacrifice of yield. From the quantitative survey a most important fact came to light, namely that the pods containing a heavy weight of cacao contain also larger beans than the average. Thus by the method adopted in the selection of high yielders, quality, so far as it depends on size of bean, is automatically improved, and the trees producing the smallest beans are excluded. This observation confirmed the method of first selection on pod value as appropriate. (1932 Report.)

7. *Second Selection on Bearing.*

In the second stage, the 1,000 trees selected on pod value are being reduced to 100 on final yield. As most of the first tagging was completed in 1933, there will be at the end of the current (1934-35) crop three years' actual yields recorded for most of the 1,000, and the reselection will be completed on those figures. The figure of 100 has been fixed in deference to the fact that the only final proof of a tree's value is the behaviour of its progeny. This test has still to come, and sufficient selections must be kept in hand to allow ruthless elimination of any that fail under it. There must then be enough still left to include types of differing agricultural characteristics, for a good tree in one district may be a poor one for another, and no single " best " type can possibly be found for all the conditions under which cacao is grown even in Trinidad, much less in the Empire.

The procedure during re-selection has taken account of yield per acre rather than yield per tree. This of course cannot be done precisely, but trees on Trinidad estates vary very much in age and size, and heavy bearers are often found to be large specimens occupying two, three or four times their fair share of the land. Such trees have been handicapped on the selector's estimate of the area effectively occupied, and unless their gross yields are really extraordinary they commonly fail to pass the standard. The standard is an estimated yield of one ton of dry cacao per acre, calculated from number of pods reaped, pods to the pound, and ground occupied. For a normal tree at 12 × 12 ft. spacing this represents 7 lb. or 50 pods (approximately) and it is a little startling at first to find 50-pod and 100-pod trees ranking as more efficient than most 200-pod trees. Where the latter require 10 to 12 pods to the pound and occupy some 24 × 24 ft. however, as they often do, there is no escaping the fact of their lower true yield. Their actual efficiency is further reduced by the lower quality of their produce in nearly all cases, and by the greater cost of harvesting and breaking twice as many pods to obtain an equivalent weight of cacao.

There has been no difficulty whatever in finding sufficient good bearers among the 1,000 trees originally tagged to make up the 100 second selections. This may be partly due to the fact that no tree was tagged at all unless it had a fair crop of pods at the time its pod value was measured. Selection rules are not hard and fast in both directions, and at each stage thought has been devoted to accelerating the next. It should perhaps be mentioned that the 100 trees given I.C.S. (Imperial College Selection) numbers occur scattered over many plantations, on all kinds of soils and under various conditions. In all cases they far outstrip their immediate neighbours in yield, so that there is no reason to suspect a specially good soil " pocket " as the cause of their high performance. Further, those which have been tagged long enough for the observation of several successive crops have yielded in many cases more than the quantity of cacao originally estimated and none of them has fallen seriously short in any year. The calculated yield of many is well above the one-ton standard, but 30 cwt. seems to be about the upper limit of potential yield under present conditions. As this is at least ten times the present average, it allows ample margin for progeny to drop below the performance of their parents and still give substantial increases. The most interesting feature of the information obtained to date is perhaps the virtual absence of antagonism between yield and quality as expressed by bean size. The selection standard of $7\frac{1}{2}$ pods to the pound has been lowered in a few cases to admit a certain number of high yielders of second class beans, which may be useful types for some localities, yet the yield of these in no case exceeds that of the best of the first class trees. (1933 and 1934 Reports.)

8. *Comparisons of Progenies.*

The crucial test of our selections remains to be made, and depends on the continuation of the Cacao Research Scheme, but it may be well to indicate here what we have provisionally planned

as the next step. The 100 selected trees are to be propagated vegetatively by several methods and set out in a series of field trials. A comparison will thus be obtained not only of the vegetative progenies themselves but of the propagation methods as well. There will be 100 individuals of each selection, so that when they come into bearing adequate samples may be prepared for commercial opinions. Yield, agricultural behaviour and commercial value will all be more readily assessed in this manner than could ever be the case from single trees, and the final result should be a series of standard varieties, of known characteristics, from which the grower can choose those best suited to his own estate or to particular fields on it. It may be added that seedling progenies are already being planted out on several estates, from which we hope to get information concerning the value of our selections as seed parents although we visualise the greatest improvements as likely to result from vegetative propagation, discussed in the next section.

Propagation.

The reasons for instituting research on methods of propagation may be shortly set out. Cacao, being a crop subject to cross-fertilization, will not breed true from seed, and although the seedling progenies of selected trees should be well above the average in performance, they cannot be expected to prove uniform, either in yield or in qualitative characters. Lack of uniformity in yield means loss on all those trees which are inferior to their parent, very doubtfully balanced by the chances of a few trees being superior. Lack of uniformity in other characters detracts seriously from quality, because uniformity is itself perhaps the greatest single factor in quality from the manufacturers' point of view. Uniformity in the field, with a crop like cacao, can only be obtained by some method of vegetative propagation.

This is only one aspect of the matter, and another possibly even more important at the present stage is that field experiments of any kind, leading to further knowledge, are particularly difficult when the reaction of each tree to experimental treatments varies from the reaction of its neighbours, and this must happen with seedling cacao. There is therefore a definite and economic need for vegetatively propagated cacao for experimental use, quite apart from its probable advantages in plantation practice.

One method of vegetative propagation is ready to hand in the budding of selected types on to seedling stocks. It has been shown that this method reduces the variability of the population in bearing capacity (1933 Report) and in some characters it naturally removes it altogether. It is not, however, ideal because the stocks themselves vary and induce variation in behaviour of the scions. For scientific investigations, therefore, it is highly desirable to have stocks also propagated vegetatively. This is the fundamental reason for research into new methods, but we have always had in mind the probability that new methods will benefit the grower directly as well as indirectly.

In 1930 the whole range of horticultural practice with other crops was open for investigation as to applicability to cacao. The first year's work narrowed down the issue and showed that softwood (or more strictly semi-hardwood) cuttings could be successfully rooted and afforded the most promising means to the desired end (1931 Report). In the following year the technique was improved (1932 Report) and at present we are rooting cuttings in considerable numbers for projected field experiments with the method reduced practically to routine, though there is still room for improvement. The rooting habits of the two kinds of branches that cacao trees bear have been compared (1933 Report), and the possibility of converting one kind of branch into the other has been established (1933 Report). These successes, though less spectacular than the results of genetic selection, are nevertheless real and important advances in the study of the cacao tree. They render possible comparisons of the selected trees which could not otherwise be undertaken, and they open up an enormous field of future researches which depend for their prosecution on the provision of absolutely uniform sets of trees.

Whether selected trees should be propagated on their own roots, as cuttings, or budded on to vegetatively raised stocks for the best commercial results remains to be shown in the field trials mentioned above.

Studies of Fruitfulness.

Studies of fruit setting and development are directed towards improvement of yields from established cacao no less than towards finding the best conditions for the new types that we hope will form the plantations of the future.

The most important information obtained concerns pollen compatibility, and goes far to explain the irregularities in fruit setting which are a prominent feature of the cacao crop. It was shown quite early that certain trees consistently gave poor setting from self-pollination, though they set freely when crossed with pollen from other trees (1931 Report). More extended observation showed that this self-incompatibility was widespread in Trinidad cacao, and further that there was a close connection between self-compatibility and setting, so that it is often possible to tell which trees are self-compatible and which self-incompatible by observing which are setting fruit naturally and which are not. Self-incompatible trees will set on crossing, and the fact that at many times they set little or nothing indicates that cross pollination at those times is very little in amount (1932 Report). Later it was shown that a self-incompatible condition is not necessarily permanent, but that under appropriate conditions some (perhaps all) self-incompatible trees may become self-compatible. When that happens, the tree begins to set fruit where it has formerly been almost or entirely barren (1934 Report). Work along a parallel line had meanwhile shown that plantation trees can be divided into continuous setters, fruiting

steadily through most of the season, and intermittent setters, and that the former give a much higher total yield than the latter (1932 Report). It is now evident that the continuous setters are the trees continuously self-compatible, and the problem becomes one of determining the conditions that favour maintenance of a self-compatible condition.

There is weighty evidence for the view that self-compatibility is influenced by nutrition, and this line of work brings us into close association with the activities of the Chemical Section. In collaboration with that Section and with the Trinidad Department of Agriculture a field experiment has been laid out to investigate the gross effects of mineral nutrition (applications of nitrogen, potash and phosphoric acid) on setting and fruit development, and the first results on analysis indicate that much useful information will be derived in future years (1934 Report).

Other aspects of fruitfulness that have been considered concern the pollinating agents and the heavy percentage of young fruits that commonly shrivel in the early stages of development. Advances along these lines have not been very important, but the work on compatibility goes to show that both of them are probably subordinate to setting as factors in final yield. Inefficiency of cross-pollinating agents may limit yield on self-incompatible trees, but once the trees get into a self-compatible condition adequate self pollination seems to occur, though the agents are still somewhat obscure. If self-compatibility can be induced by appropriate treatment, the identification of pollinating agents will probably cease to have any economic significance, though it will still be an interesting scientific problem. The shrivelling of young fruits is undoubtedly a serious source of loss of crop on some trees, but appears to depend very largely on environmental factors beyond control. There would at present appear more hope of compensating this loss than of avoiding it altogether. The continuously self-compatible tree seems partially to avoid heavy loss by spreading its crop over a longer period, and probably compensates such loss as it does suffer, by setting a further crop when conditions for development improve. It is thus likely that the solution of the shrivelling problem will be found in the conditions governing self-compatibility. In any event it may justly be claimed that a much more coherent picture of fruitfulness in cacao has been drawn by these researches than was available before, though much remains to be investigated.

Other Researches.

Work not directly on the main lines discussed above has included (1) A preliminary study of inheritance of pigment in cacao beans, which bears on questions of quality (1933 Report). (2) Statistical examination of yield records kindly made available by the Trinidad Department of Agriculture, directed towards determining the size of plot and layout necessary in field experiments with cacao. (*Tropical Agriculture* 9. 1932. 277.) (3) Studies of viability of cacao beans after storage and transport, designed to facilitate exchange of planting material between countries (1934 Report). (4) Examination of cacao roots for evidence of mycorrhizal infection, bearing on the general physiology of the tree (1934 Report). These are technical matters which need not be further elaborated here, though they all help forward the general objects that have been outlined.

Outlook.

This summary will have failed in its purpose if it has not suggested certain possibilities for the future of the cacao industry. Our vision of the future is of uniform fields, producing at lower costs per bag at least twice the present number of bags per acre. The cacao may be of varying qualities appropriate to different districts or countries, but will be uniform in all botanical respects within districts or at least within fields. The yields will justify intensive treatment of the trees, and limitation of cultivation to the most suitable soils and sites. Intensive methods based on further studies of fruiting will tend to reduce the present wide fluctuations of yield with season. Uniform trees will allow better adaptation of type to manufacturers' requirements and will facilitate preparations of the beans for the market. The prospect is one of greater regularity and more stability for both planter and manufacturer, and is surely worth striving for. The researches reported show that all these improvements are well within the bounds of possibility so far as Trinidad is concerned, and we believe the same principles to be applicable to other producing countries subject only to differences of standard and of detail.

The ideal is unfortunately far ahead, and one criticism of our work is that its benefits will be reaped by another generation. Even if this were true, it would be a poor reason for abstaining from research, but as a fact it is far from the whole truth. Economic benefit may be reaped from long range research long before its ultimate objects are attained. There are progressive planters who have already begun to apply the information gained in these preliminary investigations, and their action is one of the greatest encouragements the research workers could receive. A gradual replacement of the worst and most unprofitable trees can be effected without appreciable reduction of yields, and it will not be many years before the new trees begin to bear. Pending further trials of propagation methods, replacement by budded or seedling progenies of selected trees is the best that can be done. If seedlings are used, they will not be uniform in yield or in quality, but they can hardly fail to show better average performance in both respects than the worthless types they replace. In a few years we hope to have better material for further replacements.

Meanwhile, improvements of yield resulting from studies of fruitfulness are likely to afford means of increasing returns from established trees, and the progress already made encourages the hope that definite results along that line need not be long delayed.

THE CHEMICAL AND ECOLOGICAL RESEARCHES.

By F. HARDY, M.A.

(I) Objects of the Investigation.

The main object of the chemical investigations of the cacao crop is to investigate thoroughly the environment in which the cacao tree is grown, with a view to determining what are the exact atmospheric and soil conditions most conducive to high production and good quality. When these conditions have been determined accurately, steps may then be taken to improve the growth conditions in fields where cacao production is unsatisfactory, and definite advice may be offered to planters, concerning those soils and localities which would appear to be most suitable for new cacao cultivations.

The subject was approached from two main points of view, namely, (1) systematic qualitative and quantitative studies of the soils and of the atmospheric environments of two contrasted "good" and "bad" plots of established cacao in Trinidad, and (2) detailed soil surveys, within the West Indies region, of representative cacao areas of determinable reputation and performance. These preliminary investigations revealed the chief characters of a good cacao soil; they also indicated the particular external factors that mainly confer high productivity, or contrarily, that seriously limit production. The information obtained from these preliminary broad lines of research naturally led, in due course, to other more detailed investigations, many of which are still incomplete. Field experiments were laid down which comprised a series of manurial trials and trials of organic mulches. The effects of manuring and mulching were assessed, not only by records of yield increments, but also by chemical analyses of the leaves and other parts of the cacao tree, and by a systematic study of the effects produced by the manuring on the physical and chemical properties of the soil. Striking responses to manurial treatment, and definite interactions between the three chief plant nutrient substances, nitrogen, phosphate and potash, were soon revealed, leading to a further series of general manurial trials, which are still being continued.

In the following sections, a brief outline is presented of the progress which has been made and the results obtained during the period under review.

(II) Studies of the environment of the Cacao Tree.

For the purposes of this investigation, contrasted "good" and "bad" cacao plots were selected for close observation. The physical and chemical features of the soil of each plot, down to a depth of six feet, were determined, and in addition, routine measurements of the following fluctuating environmental factors were made:— (1) rainfall, (2) soil moisture, (3) level of soil water-table, (4) humidity of the air, (5) evaporating ability of the air at three different levels, (6) light intensity at three different levels, and (7) air and soil temperatures. Periodic observations were also made of the condition of the cacao trees with regard to vegetative flushing, flowering, setting of fruit and shedding of fruit.

These measurements and observations were carried out for a period of three years. The results have been fully discussed in the first three annual reports on Cacao Research; they demonstrated the remarkable effects of fluctuations in the moisture conditions of the atmosphere and of the soil on the vegetative and reproductive processes of the cacao tree, and indicated that the most suitable environment for the cacao tree is one in which moisture fluctuations are least, thus proving the value of overhead shade and windbreaks in the cacao field. Apart from the intrinsic value of these findings, the results have important application in connection with other investigations, such as those concerning the effects of manurial and cultural treatments on the growth and yield of the cacao tree. Since the fluctuations in the moisture environment have thus been shown to exert a marked effect on the setting and production of the cacao crop, detailed measurements of soil and atmospheric moisture fluctuations accordingly have been made at the sites of the later manurial experiments and mulching trials. By this means, it should eventually be possible to distinguish clearly between seasonal and environmental effects on crop production, and between the different effects of the specific experimental treatments which are being tested.

(III) Cacao Soil Surveys.

Soil surveys of important cacao-growing districts have been carried out, not only in Trinidad, but in the neighbouring West Indian islands, Tobago and Grenada. The methods by which these soil surveys have been conducted are briefly as follows: Sample pits are dug in selected sites, usually to a depth of six feet. The soil profile thus exposed usually shows marked stratification into more-or-less distinct but merging layers. The topmost layer is rich in organic matter derived from decaying vegetation; it has been found to be particularly important, since it contains the bulk of the nutrients on which the cacao tree thrives. The soil profile is described in field notes, and soil samples, representing the different layers, are collected for laboratory examination, usually about ten for each profile. In the laboratory, the following routine determinations are made by the analytical staff of the College Chemistry Department:—

(*a*) Reaction; degree of acidity or alkalinity; (*b*) Texture; degree of sandiness or clayiness; (*c*) Calcium carbonate (free lime) content; (*d*) Organic matter content; (*e*) Available water-soluble plant nutrients; (*f*) Total nitrogen; (*g*) Available phosphate; (*h*) Available potash.

During the course of the cacao soil surveys, profile samples have been obtained at 178 different sites, giving approximately 1,780 soil samples for analysis in the laboratory. For purposes of comparison, these sites were divided into "good" and "bad," depending on the recorded yields of the cacao trees. The conclusions concerning the characters of good cacao soils are thus based on the chemical analysis of a large number of soil samples taken from contrasted high-yielding and low-yielding areas. The experimental methods and results have been fully described in special reports*, and in the First, Second, Third and Fourth Annual Reports on Cacao Research. Many of the findings may be directly applicable in cacao-growing regions occurring in other parts of the world, since they appear to be fundamental, as well as peculiar to the cacao crop.

(IV) Physical and Chemical features of Good Cacao Soil.

(1) *Soil Reaction; Degree of Acidity or Alkalinity.*

The cacao tree appears to be tolerant of a wide range of soil reaction, the optimum reaction being slightly on the acidic side of neutrality. A highly acidic reaction occurring in heavy clay soils may be taken as a sign of physical conditions of the soil unsuitable for the growth of cacao.

(2) *Texture; Degree of Sandiness or Clayiness.*

One of the primary requirements of a good cacao soil is an even moisture status, that is, the soil must not dry out quickly, nor be subject to waterlogging during wet weather. Optimum texture conditions will therefore vary with climatic and environmental factors. Good natural drainage is essential, but light sandy soils are only suitable for the growth of cacao in well-sheltered moist environments.

(3) *Calcium Carbonate (Free lime) Content.*

The lime content of cacao soils does not appear to exert an important influence on their fertility, since productive cacao occurs both on calcareous and on non-calcareous soils. The exact rôle of calcium in cacao nutrition is not yet understood; it is at present being tested by a number of detailed experiments.

(4) *Organic Matter Content and Carbon/Nitrogen Ratio.*

High-yielding cacao soils generally have a high content of organic matter in their surface layers. The conservation of the surface layer of litter or decomposing vegetation appears to be a very important factor in the maintenance of high yields in West Indian cacao fields. Moreover, the ratio of carbon to nitrogen of this organic matter is generally much higher in the case of good yielding fields than in poor yielding fields.

(5) *Harmful Factors.*

In a number of clay soil-types occurring in Trinidad, poor growth and yield of cacao are often associated with a high content of the natural mineral, gypsum (soluble calcium sulphate), present in the sub-soil layers. This has led to the conclusion that excessive quantities of calcium sulphate in the soil may adversely effect the growth and yield of cacao. The exact manner in which this harmful effect takes place is not yet understood, but the matter appears to be of great practical importance, in view of the high sulphate content of commercial artificial manures, such as superphosphate (which contains 50 per cent. calcium sulphate), ammonium sulphate and potassium sulphate. A number of experiments have been designed, and are now being carried out, in order to discover the reason for the harmful effect of excessive sulphate on the cacao tree.

(6) *Total Nitrogen.*

West Indian cacao soils appear to be generally well supplied with nitrogen, no definite differences having been found between the nitrogen contents of high and of low yielding soils.

(7) *Available Phosphate.*

One of the most striking features revealed by the examination of West Indian cacao soils is a marked deficiency of available phosphate in the poorer types of soil. Conversely, high yielding soils generally have a high available phosphate content. Very few exceptions to this rule have been discovered, at least for the heavier kinds of cacao soil.

(8) *Available Potash.*

Adequate supplies of available soil potash are essential for the optimum growth and yield of the cacao tree. Certain sandy types of soil in Trinidad are markedly deficient in potash, but this condition is not nearly so widespread as phosphate deficiency in the areas so far surveyed.

(9) *General Nutrient Status of West Indian Cacao Soils.*

The evidence obtained from the soil investigations has revealed an *unbalanced* nutrient supply in the less-fertile cacao soils of the areas so far surveyed. Nitrogen appears to be present in these soils in adequate amounts relative to phosphate and potash. This circumstance may be due partially to the customary practice of planting leguminous shade trees in the cacao fields, thereby subjecting the soil to continuous

* Studies in West Indian Soils; (III) Cacao Soils of Tobago; (IV) Cacao Soils of Grenada; (VII) Cacao Soils of Trinidad, (A) Montserrat District, by F. Hardy, J. A. McDonald, G. Rodriguez, *et al.*, Reports published by Editorial Department, Imper. Coll. Trop. Agric., Trinidad, in 1931, 1932 and 1933.

mulching with highly nitrogenous material, consisting of leaves, flowers and twigs dropped from the shade trees. The shade trees often grow to the size of large forest trees; they must take up considerable quantities of plant nutrients from the soil. Being leguminous, they are able to manufacture their own nitrogen supply, but they are wholly dependent on the soil for their supplies of phosphate and potash. Thus they may deplete the soil of cacao fields of phosphate and potash relative to nitrogen. Whatever the causes of the condition, it is now definitely established that many West Indian cacao soils are suffering from a lack of balance in their nutrient supply. From a practical point of view, therefore, full benefit cannot be expected from the application to the soil of haphazard or arbitrary manurial mixtures. The common practice of using general "complete" manures may be particularly wasteful, since one of the ingredients of the complete manure may already be present in the soil in adequate or even excessive amounts relative to the other nutrients. Improvement of yield by means of manuring must consist of applying nutrient substances in correct proportion, so that the nutrient balance of the soil may be restored.

(V) Manurial experiments on Cacao in Trinidad.

A number of field manurial trials were initiated at the beginning of 1932, in order to test some of the main findings of the detailed soil investigations. The first series of field experiments solely concerned the phosphate factor, since deficiency of this nutrient appeared to be the most serious factor limiting crop production. Other field experiments were subsequently laid down to test (*a*) the comparative effect of different types of phosphatic manure, (*b*) the effect of organic matter, (*c*) the effect of nitrogenous, phosphatic and potassic manures, both alone and in combination, and (*d*) the comparative effect of artificial manures on shaded and un-shaded cacao. The results so far obtained are presented in detail in the Fourth Annual Report on Cacao Research. The preliminary results have shown that very striking improvement in the yield of established cacao may be obtained by the proper use of artificial manures that rectify known nutrient deficiencies. On certain phosphate-deficient soils, yield increases of over one hundred per cent. have been obtained by the use of superphosphate manure alone, and within one year of the first application. A manurial experiment carried out by the Botanical Section on a potash-deficient soil, similarly gave large increases in yield from potash manuring. Such striking improvements in yield have not been confined only to quantitative increases, but evidence has been obtained that the use of artificial manures has improved the *quality* of the cacao produced, as shown by an increased size of bean. No direct evidence has yet been obtained, however, of the beneficial effect of organic mulches on the yield of cacao. Critical experiments with mulches necessarily require considerable time for completion, and the experiments have only recently been inaugurated. Certain other manurial matters still require investigation. For instance, for phosphate-deficient soils, further additional increases in yield may be obtained from potash and nitrogen manuring, provided the phosphate deficiency has first been remedied. Again, evidence has been obtained of a reciprocal relationship between potash and lime in cacao nutrition, and the requirements of the cacao tree for potassium may vary considerably depending on the calcium content of the soil. The possibly harmful effect of calcium sulphate, and the effect of artificial manures in the presence and absence of this substance, are also being studied by means of field experiments.

(VI) Pot Tests for Soil Fertility.

The chemical tests usually applied to determine the content of available plant nutrients in the soil sometimes give misleading results. This is due to the fact that plant nutrients are often present in the soil in a form unavailable to the plant, and chemical tests do not always clearly distinguish between available and unavailable nutrients. Accordingly agricultural research workers have lately developed a number of pot tests, which depend on the plant itself as a test of soil fertility. Investigations carried out in Trinidad on these lines in connection with cacao soils, have developed a sensitive pot test for assessing available phosphate contents. This test depends on the peculiar sensitivity of young tomato plants to phosphate deficiency, and it offers a simple method whereby the planter can test his soils for phosphate deficiency, without recourse to chemical procedures. The method has been fully described in an article published in *Tropical Agriculture*, Vol. X, No. 4, 1933, p. 108.

(VII) Chemical Analysis of Cacao Leaves.

A further contribution to the solution of the general question of the nutritional requirements of the cacao tree is being sought in the chemical analysis of leaf material obtained from trees growing in the plots of the various manurial experiments. This method aims at diagnosing nutritional deficiencies in the soil by a determination of the chemical composition of the ash of the leaves. Such a procedure has elsewhere yielded valuable results for other orchard crops, such as the apple, provided a satisfactory basis for comparison can be obtained. The results of these investigations are fully described in the Second, Third and Fourth Annual Reports on Cacao Research. The chemical composition of different parts of the cacao tree is evidently largely influenced by the nutrient supply in the soil, and the chemical analysis of cacao leaf tissue has proved to be a reliable guide to the manurial requirements of the crop. The proportion of nitrogen to potassium in the leaf appears to be a

valuable index of the condition of the tree, both with regard to yielding capacity and general vigour. Leaf analysis has indicated that somewhat unexpected results may follow when different manures are applied to a particular soil. Thus, in one experiment, the addition of superphosphate manure resulted, not only in an increased uptake of phosphate by the cacao tree, but also in an increased uptake of potash, although no potash manure was applied.

(VIII) Sand and Water Culture Experiments.

By growing plants in pure sand or water cultures, the amount of a particular nutrient substance available to the plant may be varied at will. This method has therefore been used to study the effects of deficiencies of various nutrient substances on the growth and appearance of young cacao plants.

Nutrient deficiencies often reveal themselves by characteristic symptoms affecting the appearance of the plant. Thus, a particular kind of leaf-scorch affects fruit crops grown in England under conditions of soil potash deficiency, and nitrogen-deficient soils often impart an unhealthy pale-green colour to the leaves of plants supported by them. In order to ascertain whether similar symptoms affect cacao, special water culture and sand culture experiments were initiated. Some striking preliminary results of this phase of the cacao investigations are presented in the Fourth Annual Report on Cacao Research. Definite leaf markings and growth characteristics have been demonstrated for potassium deficiency and nitrogen deficiency respectively. The practical utility of these findings lies in the possibility of diagnosing nutrient deficiencies in the field, merely by observing growth characteristics and leaf markings similar to those obtained in the sand cultures. The recorded symptoms of potassium deficiency and nitrogen deficiency are very distinctive and easily recognised ; they should be particularly useful for field diagnostic purposes. Leaf scorch symptoms of potassium deficiency have been observed in the field where the soil is known by chemical tests to be deficient in available potash.

(IX) Future Outlook.

As a result the investigations above described, it is now possible to state with some degree of certainty whether a particular soil or a particular locality is suitable for the successful cultivation of productive cacao. Future investigations may develop newer and better methods for assessing the characters of soil and environment. The importance of this line of research is obvious, since the proper application of the results already obtained to cacao growing areas in other parts of the world will depend on the accurate determinations of soil and environmental characteristics in each particular area. For those areas where cacao has already been established, the detailed examination of soil and environment is an essential preliminary to any scheme which aims at the quantitative or qualitative improvement of the yield of cacao. Even when naturally high-yielding strains are available to planters, their successful exploitation in countries where soil and atmospheric conditions may vary very widely, will ultimately depend on proper field procedures, involving the provision of suitable shelter, shade, and drainage, and the choice and application of the right assortment of manures.

The results so far obtained from manurial experiments in Trinidad show that such detailed investigations are eminently worth while. The yield of established cacao may be more than doubled within one year by suitable manurial treatments in some instances, whilst the quality of the product may also be improved. Such striking increases in yield have been obtained simply by supplying nutrient substances which were shown by chemical tests to be deficient in the soil. There are many aspects of cacao production which remain to be investigated by chemical methods. In particular, further evidence is required on the effect of manurial substances on the *quality* of the product, and the possible difference in chemical composition of high and low quality cacao. The exact rôle of organic matter in cacao nutrition has still to be eluc dated, and, from a more immediately practical viewpoint, the best and most economic types of commercial fertilisers must be identified. These and other problems are being investigated largely by means of field experiments, but also by means of sand culture experiments and laboratory investigations. Indeed, the three methods of attack are frequently applied to the same problem, since field experiments and sand culture experiments provide material for laboratory examination.

The field experiment takes prior place in the present and contemplated future researches for many reasons. For example, it gives quantitative evidence concerning the practical utility of a particular treatment suggested by more academic investigations, and secondly, it also provides, for detailed chemical examination, soil and plant material from areas or plots where accurate yield data are available. By such means, it is possible to correlate chemical characters of soil and plant with yield or quality of the cacao produced. These are only broad indications of the course of future researches ; as time goes on, the results of existing investigations must inevitably present new problems, and show existing problems in a new light. The chemical researches so far have clearly demonstrated the important part played by environment and nutrient supply in building up the cacao crop, and have also demonstrated the practical possibility of improving the yield of cacao by the proper application of the results of field and laboratory investigations.